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(FORM UPDATED: 08/11/2010)

WISCONSIN STATE LEGISLATURE ...
PUBLIC HEARING - COMMITTEE RECORDS

2011-12
(session year)

Assembly
(Assembly, Senate or Joint)

Committee on Natural Resources...

COMMITTEE NOTICES ...

- Committee Reports ... **CR**
- Executive Sessions ... **ES**
- Public Hearings ... **PH**

INFORMATION COLLECTED BY COMMITTEE FOR AND AGAINST PROPOSAL

- Appointments ... **Appt** (w/Record of Comm. Proceedings)
- Clearinghouse Rules ... **CRule** (w/Record of Comm. Proceedings)
- Hearing Records ... bills and resolutions (w/Record of Comm. Proceedings)

(**ab** = Assembly Bill)	(**ar** = Assembly Resolution)	(**ajr** = Assembly Joint Resolution)
(**sb** = Senate Bill)	(**sr** = Senate Resolution)	(**sjr** = Senate Joint Resolution)

- Miscellaneous ... **Misc**

* Contents organized for archiving by: Stefanie Rose (LRB) (August 2013)

Assembly

Record of Committee Proceedings

Committee on Natural Resources

Assembly Bill 23

Relating to: disinfection of municipal water supplies.

By Representatives Severson, Rivard, Ballweg, Bernier, Bies, Jacque, Krug, LeMahieu, Marklein, Mursau, Murtha, Thiesfeldt, Tiffany and Ziegelbauer; cosponsored by Senators Harsdorf, Galloway, Moulton, Olsen, Schultz, Grothman and Holperin.

February 17, 2011 Referred to Committee on Natural Resources.

March 30, 2011 **PUBLIC HEARING HELD**

Present:	(15)	Representatives Mursau, Rivard, Williams, Kleefisch, Nerison, J. Ott, Severson, Steineke, Tiffany, Mason, Molepske Jr, Danou, Clark, Milroy and Hulsey.
Absent:	(0)	None.
Excused:	(0)	None.

Appearances For
- Erik Severson, Madison — Representative, 28th Assembly District
- Sheila Harsdorf, Madison — Senator, 10th Senate District
- Louis Muench, Cumberland — Cumberland Municipal Utility

Appearances Against
- Madeline Gotkowitz, Madison
- Mariah Clark, Middleton

Appearances for Information Only
- Ken Bradbury, Brooklyn
- Sarah Nunn, DePere — Cumberland Utilities

Registrations For
- Jim Holperin, Madison — Senator, 12th Senate District
- Curt Witynski, Madison — League of Municipalities

Registrations Against
- Lori Grant, Madison — River Alliance of Wisconsin
- Jennifer Giegerich, Madison — Wisconsin League of Conservation Voters

- Penny Bernard Schaber, Madison — Representative, 57th Assembly District
- Madeline Gotkowitz, Madison — Mark Borchert
- Lynn Legler, Madison
- Maureen Early Ruzicka, Madison

Registrations for Information Only

- None.

April 27, 2011 **EXECUTIVE SESSION HELD**

Present:	(15)	Representatives Mursau, Rivard, Williams, Kleefisch, Nerison, J. Ott, Severson, Steineke, Tiffany, Mason, Molepske Jr, Danou, Clark, Milroy and Hulsey.
Absent:	(0)	None.
Excused:	(0)	None.

Moved by Representative Rivard, seconded by Representative Kleefisch that **Assembly Amendment 1** be recommended for adoption.

Ayes:	(15)	Representatives Mursau, Rivard, Williams, Kleefisch, Nerison, J. Ott, Severson, Steineke, Tiffany, Mason, Molepske Jr, Danou, Clark, Milroy and Hulsey.
Noes:	(0)	None.

ASSEMBLY AMENDMENT 1 ADOPTION RECOMMENDED, Ayes 15, Noes 0

Moved by Representative Kleefisch, seconded by Representative J. Ott that **Assembly Bill 23** be recommended for passage as amended.

Ayes:	(9)	Representatives Mursau, Rivard, Williams, Kleefisch, Nerison, J. Ott, Severson, Steineke and Tiffany.
Noes:	(6)	Representatives Mason, Molepske Jr, Danou, Clark, Milroy and Hulsey.

PASSAGE AS AMENDED RECOMMENDED, Ayes 9, Noes 6

Tiffany

Tim Gary
Committee Clerk

Vote Record
Committee on Natural Resources

Date: April 27, 2011

Moved by: Rivard   Seconded by: Kleefisch

AB 23   SB ____   Clearinghouse Rule ____

AJR ____   SJR ____   Appointment ____

AR ____   SR ____   Other ____

A/S Amdt 1

A/S Amdt ____ to A/S Amdt ____

A/S Sub Amdt ____

A/S Amdt ____ to A/S Sub Amdt ____

A/S Amdt ____ to A/S Amdt ____ to A/S Sub Amdt ____

Be recommended for:

☐ Passage ☒ Adoption ☐ Confirmation ☐ Concurrence ☐ Indefinite Postponement

☐ Introduction ☐ Rejection ☐ Tabling ☐ Nonconcurrence

Committee Member	Aye	No	Absent	Not Voting
Representative Jeffrey Mursau, Chair	☑	☐	☐	☐
Representative Roger Rivard	☑	☐	☐	☐
Representative Mary Williams	☑	☐	☐	☐
Representative Joel Kleefisch	☑	☐	☐	☐
Representative Lee Nerison	☑	☐	☐	☐
Representative Jim Ott	☑	☐	☐	☐
Representative Erik Severson	☑	☐	☐	☐
Representative Jim Steineke	☑	☐	☐	☐
Representative Thomas Tiffany	☑	☐	☐	☐
Representative Cory Mason	☑	☐	☐	☐
Representative Louis Molepske Jr	☑	☐	☐	☐
Representative Chris Danou	☑	☐	☐	☐
Representative Fred Clark	☑	☐	☐	☐
Representative Nick Milroy	☑	☐	☐	☐
Representative Brett Hulsey	☑	☐	☐	☐
Totals:	15	0		

☒ Motion Carried   ☐ Motion Failed

Vote Record
Committee on Natural Resources

Date: April 27, 2011
Moved by: Kleefisch Seconded by: Ott

AB 23 SB ____ Clearinghouse Rule ____
AJR ____ SJR ____ Appointment ____
AR ____ SR ____ Other ____

A/S Amdt ____
A/S Amdt ____ to A/S Amdt ____
A/S Sub Amdt ____
A/S Amdt ____ to A/S Sub Amdt ____
A/S Amdt ____ to A/S Amdt ____ to A/S Sub Amdt ____

Be recommended for:
☒ Passage ☐ Adoption ☐ Confirmation ☐ Concurrence ☐ Indefinite Postponement
☐ Introduction ☐ Rejection ☐ Tabling ☐ Nonconcurrence

Committee Member	Aye	No	Absent	Not Voting
Representative Jeffrey Mursau, Chair	☒	☐	☐	☐
Representative Roger Rivard	☒	☐	☐	☐
Representative Mary Williams	☒	☐	☐	☐
Representative Joel Kleefisch	☒	☐	☐	☐
Representative Lee Nerison	☒	☐	☐	☐
Representative Jim Ott	☒	☐	☐	☐
Representative Erik Severson	☒	☐	☐	☐
Representative Jim Steineke	☒	☐	☐	☐
Representative Thomas Tiffany	☒	☐	☐	☐
Representative Cory Mason	☐	☒	☐	☐
Representative Louis Molepske Jr	☐	☒	☐	☐
Representative Chris Danou	☐	☒	☐	☐
Representative Fred Clark	☐	☒	☐	☐
Representative Nick Milroy	☐	☒	☐	☐
Representative Brett Hulsey	☐	☒	☐	☐
Totals:	____	____	____	____

☒ Motion Carried ☐ Motion Failed

WISCONSIN STATE LEGISLATURE

CUMBERLAND MUNICIPAL UTILITY

Charles Christensen,
General Manager

March 28, 2011

Dear Senators and Representatives
of the State of Wisconsin:

RE: SENATE BILL 19, ASSEMBLY BILL 23

We would like to take this opportunity to thank you for signing on and co-sponsoring the above bills. Senate Bill 19 and Assembly Bill 23 are of the utmost importance to our small community in northwest Wisconsin. Cumberland is proud if its drinking water supply and quality, as most communities in northern Wisconsin are. It was a memorable moment for our community last year, when it was chosen by the Rural Water Association as having the 3rd Best Tasting Water in the State of Wisconsin.

In most small communities, the certified waterworks operators are known on a personal level by many of its citizens. We can assure you that in Cumberland, along with all of the other operators that we know, none of the operators or the communities that they represent, take a chance on not disinfecting their systems if they had a proven reason to do so. All of the small communities currently have some form of emergency disinfection available to them, as per DNR rules.

Continuous disinfection of water systems is a much different situation, as it requires more sophisticated monitoring equipment, added storage for chemicals, the possibilities of adding additional chemical treatment for such things as Manganese, that may be currently present but will be intensified by the additional disinfection. Continuous chlorination brings a "continuous expense" to small utilities and communities that are already currently struggling under budget constraints.

When the DNR rule for continuous disinfection of all water systems was passed, members of the Senate indicated that cities affected by the rule would be in a position to receive DNR funding to mitigate the impact on local budgets. We made application for funding, however that response has not been forthcoming from the DNR.

We were also assured that should we utilize a UV disinfectant system, the DNR rule requiring minimum continuous chlorination could be waived. We have not received any assurances that this is a fact.

P.O. Box 726 • Cumberland, WI 54829 • Office: 822-2595 — 24 Hour: 822-8298

Northern Wisconsin has long been an attraction for tourists, due to its pristine waters, abundant wildlife and public lands. Chlorine tasting water does not seem to have a place in this setting. Many of our citizens have approached us, stating the cost of purchasing bottled water and water filtration systems to remove the chlorination puts additional stress on already tight personal budgets.

If we were assured that we were putting our customers in danger of a health risk by not continuously chlorinating or disinfecting our water system, we would feel that we should take immediate action to correct it and not wait two to three years for the rule to take affect. However, we do also believe that if this was a serious health risk, it would be affecting private wells and private water systems, such as mobile home parks, camp grounds, etc., and that the EPA would require it nation wide. This is not the case.

We have included an article addressing disinfection by-product challenges in drinking water, which highlights some of the effects that can be encountered with chlorination of a water supply. We have also included our "response" to comments made at a DNR Liaison Committee Meeting earlier in reference to these bills.

Thank you, once again, for supporting these important bills.

Very truly yours,

Charles Christensen

Charles Christensen, Manager
Cumberland Municipal Utility

Very truly yours,

Dean Bergstrom

Dean Bergstrom, Chief Operator
Cumberland Municipal Utility

CC/DB/kh

Enc.

CUMBERLAND MUNICIPAL UTILITY

Charles Christensen,
General Manager

March 24, 2011

RESPONSE TO DNR COMMENTS
ON ASSEMBLY BILL 23 & SENATE BILL 19

It is our understanding that at the DNR Liaison Committee Meeting, Mr. Lee Boushon of the DNR, raised concerns that this legislation would go further than the proposed rule. Mr. Boushon's concern indicated that the DNR can now allow a well to be used with insufficient casing, if disinfection is provided. Under the Rule, the DNR could not mandate disinfection in these types of scenarios. Therefore the DNR would not be able to give utilities the flexibility to have or use different construction or treatment.

We believe this is in error, as the EPA Groundwater Rule allows States to determine the frequency of monitoring/sampling of groundwater sources, based on the history of testing and the degree of risk for the system to have non-compliant water quality. If non-compliant water quality is found, the Groundwater Rule gives States the authority to require immediate corrective action.

In the response to the statement that the DNR would not be able to mandate disinfection in cases where insufficient well casing is provided, there are a few different issues. Although the DNR could not require disinfection for the simple reason that the casing is more shallow, they could require additional/more frequent sampling of the groundwater, because this could be considered a high risk situation. If any of the groundwater samples were found to be unsafe, the DNR could then mandate disinfection, or order other immediate corrective action.

Therefore, it would appear as though the concerns expressed by the DNR are addressed within the EPA Groundwater Rule, which is in effect at the national level.

Sincerely,

Charles Christensen
General Manager

Sincerely,

Dean Bergstrom
Certified Waterworks Operator

P.O. Box 726 • Cumberland, WI 54829 • Office: 822-2595 — 24 Hour: 822-8298

Addressing Disinfection By-Product Challenges in Drinking Water

By Leo Zappa and William Zavora

For over one hundred years, the predominant disinfectant chemical has been chlorine. While a highly effective disinfectant, chlorine has been found to react with naturally occurring matter (NOM) in the water to form disinfectant by-products (DBPs). DBPs have been linked to a number of human health concerns and have been regulated by the United States EPA. Public water system operators will soon face compliance with the U.S. EPA's Stage 2 Disinfectants and Disinfectant By-products Rule (US-EPA Stage 2 DBPR). Specifically, water utilities will be required to achieve locational running annual averages of 80 ug/l for total trihalomethanes (TTHM) and 60 ug/l for haloacetic acids (HAA5) starting in 2012.

One of the methods employed by some water utilities to come into compliance with US-EPA Stage 2 DBPR is to switch disinfectant chemicals, moving away from chlorine and converting to alternative means of disinfection such as chloramine. It is known that chloramines can provide satisfactory disinfection while producing lower levels of TTHMs and HAA5s. However, recent research has discovered that use of the alternate disinfectant, while reducing the levels of the currently regulated DBPs, can have unintended consequences. Specifically, the use of chloramines can lead to the formation of new classes of DBP's.

These emerging, and currently unregulated DBPs, can include nitrogen and iodine-based compounds (N-DBPs, Iodo-DBPs). Examples of these new DBPs include iodo acids such as iodoacetic acid, iodo-THMs such as dichloroiodomethane, haloaldehydes, halomides, and NDMA. The formation potential of these emerging DBPs is enhanced by the increased use of impaired waters as supplies of pristine waters decrease. Impaired waters can encompass such factors as the impact of wastewater (including the reuse of wastewater in states such as Florida and California) and algal growth. Impaired waters often have heightened levels of organic nitrogen, which provides precursors for nitrogenous DBPs.

The major concern regarding these new classes of DBPs is their toxicity to humans. Current research is focused on determining the cytoxicity and genotoxicity of these emerging DBPs. Cells exposed to a cytotoxic compound can suffer necrosis, where the cell membrane loses integrity and dies. In contrast, cells exposed to genotoxic compounds can suffer genetic mutations, which can in turn lead to the formation of cancerous tumors.

A number of the emerging N-DBPs and iodo-DBPs appear to be significantly more genotoxic and cytotoxic than the currently regulated TTHMs and HAA5s. Examples include halonitromethanes, which appear to be up to 10 times more cytotoxic than regulated THMs, and iodo-acids, which have been shown to be twice as genotoxic as the currently regulated DBPs.

Due to the competing demands to provide safe, disinfected drinking water to their customers while at the same time meeting current DBP regulations and limiting the formation of emerging DBPs, municipal water providers are investigating other means to prevent or limit DBP formation. One such alternative approach is the removal of naturally occurring matter (NOM) from the water prior to adding disinfectant chemicals. By removing the organic precursors, the formation potential for DBPs, both regulated and emerging, is greatly reduced.

There are a number of technologies which have been evaluated and are now being employed by municipal water providers for precursor removal. Membrane filtration, activated carbon, and the enhanced coagulation process have emerged as the three most commonly applied technologies for NOM reduction. All three of these technologies have been thoroughly researched for their effectiveness relative to NOM reduction, and there are numerous technical papers which describe how these technologies can be applied to help municipalities meet their Stage 2DBPR compliance requirements.

A key feature common to these technologies is that they are able to accomplish the goal of meeting current DBP regulations without any detrimental side-effects, such as the formation of emerging disinfection by-products. Another point worth noting is that each of these technologies and processes were originally developed to accomplish other water quality goals, but have been repurposed to provide a solution to the Stage 2 DBPR challenge.

Municipal water providers are presented with the dilemma of balancing the need for supplying disinfected water with the prevention of forming hazardous disinfection by-products. Short term solutions such as switching disinfectant chemicals may be relatively inexpensive and easy, but can create as many problems as they solve. The long term solution to this challenge should be to encourage the water industry to research and develop innovative approaches to applying new and existing technologies. Emphasis should be placed on those technologies and processes that reduce or remove contaminants and precursor compounds from water in lieu of adding more chemicals to our drinking water. ●

WISCONSIN STATE LEGISLATURE

WISCONSIN LEGISLATIVE COUNCIL

Terry C. Anderson, Director
Laura D. Rose, Deputy Director

TO: REPRESENTATIVE ERIK SEVERSON

FROM: Rachel Letzing, Senior Staff Attorney

RE: Assembly Amendment ___ (LRBa0591/1) to 2011 Assembly Bill 23, Relating to Disinfection of Municipal Water Supplies

DATE: March 28, 2011

At your request, this memorandum describes Assembly Amendment ___ (LRBa0591/1) to 2011 Assembly Bill 23, relating to disinfection of municipal water supplies.

Current Law

Under current law, the Department of Natural Resources (DNR), after a public hearing, is required to: (1) prescribe, publish, and enforce minimum reasonable standards and methods to be pursued in obtaining pure drinking water for human consumption; and (2) establishing all safeguards deemed necessary in protecting the public health against the hazards of polluted sources of impure water supplies intended or used for human consumption. [s. 280.11 (1), Stats.] The DNR is authorized to establish, administer, and maintain a safe drinking water program no less stringent than the requirements of the Safe Drinking Water Act. [s. 281.17 (8) (a), Stats.] Under this statutory authority, the DNR promulgated ch. NR 810 – Requirements for the Operation and Maintenance of Public Water Systems.

In the 2009-10 legislative session, the DNR under Clearinghouse Rule 09-073 proposed numerous changes to administrative rules relating to safe drinking water, design requirements for community water systems, and to ch. NR 810. Included in the changes to ch. NR 810 was a new provision which requires municipal drinking water systems, by December 1, 2013, to provide continuous disinfection of the water prior to entry to the distribution system. This modified rule became effective on December 1, 2010.

The Bill

The bill creates a new provision which specifies that, notwithstanding the statutes listed above, the DNR is prohibited from requiring a municipal water system to provide continuous disinfection of the water that it provides, unless continuous disinfection is required under federal law.

The Amendment

The amendment modifies the prohibition in the bill to provide that the DNR is prohibited from requiring a municipal water system to provide continuous disinfection of the water that it provides, unless one of the following applies:

- Continuous disinfection is required under federal law.

- Water quality data, well construction, or water system construction indicate a potential health hazard.

The amendment also adds a provision to the bill regarding the priority list DNR must establish to rank each safe drinking water loan program project. The amendment specifies that for the purpose of ranking safe drinking water loan projects, in addition to the current requirements, the DNR is required to treat a project to upgrade a public water system to provide continuous disinfection of the water that it distributes as if the public water system were a surface water system that the federal law requires to provide continuous disinfection. According to DNR staff, this language is intended to maintain the status quo regarding the ranking of safe drinking water loan projects.

If you have any questions, please feel free to contact me directly at the Legislative Council staff offices.

REL:ksm:wu


FORWARD
E PLURIBUS UNUM

Louie's Finer Meats

Hwy 63 N.
P.O. Box 774
Cumberland, WI 54829

715.822.4728
715.822.3150 fax
www.louiesfinermeats.com

March 28, 2011

Dear Representatives of the State of Wisconsin:

RE: Senate BIll 19, Assembly Bill 23

This letter is written to take the opportunity to thank-you for signing on, supporting and co-sponsoring Senate Bill 19 and Assembly Bill 23 on behalf of Louie's Fine Meats, Inc. of Cumberland, Wisconsin.

Along with many other Wisconsin communities, the Cumberland area is very fortunate to have a high quality water supply from groundwater. Many visitors to the community comment on the high quality of the existing municipal water supply. There is no history of routine problems with our community's water supply and continuous chlorination is unnecessary. We share the concern in guaranteeing a safe water supply for Wisconsin residents, but this one-size-fits-all regulation is the wrong approach for a number of reasons. Cumberland Municipal Utility is already equipped to chlorinate water in emergency situations. Water quality is continuously monitored by the DNR and our tap water is tested by the Wisconsin Dept. of Agriculture.

The existing high-quality water resources have benefited the local economy, including Louie's Finer Meats. Our business has been recognized with over 300 state, national, and international awards for producing high quality meat products. Our company employs 40 people in the City of Cumberland. Water is an important component of the manufacture of meat products. For over 40 years, this company has been able to meet our water needs by simply using the municipal water supply. Water is used as an ingredient in most processed meat products to assist in dispersal of other ingredients. Using a lower quality or chlorinated water impacts the flavor, texture, and color of the product. Compounding the issue, some of our products require the use of active lactic acid starter cultures. These expensive cultures cannot be mixed with chlorinated water, since the chlorine will kill the live cultures. If our municipal water is continuously chlorinated, we will be forced to purchase distilled water or remove the chlorine from the tap water prior to using it for processing. This will add unnecessary costs and inconveniences to our operations. One method of removing chlorine from water is allowing it to sit in a cistern or container to "draft off" the chlorine into the air over a period of time. This step may actually increase the risk of contamination. Several other Cumberland businesses will also be impacted by this, be it other food processors, restaurants, greenhouses, or biodeisel and canning factories.

The proposed regulation will also produce a more general impact on the local economy. By mandating continuous chlorination, large costs will be imposed on the Cumberland Municipal Utility. Additional costs must be passed down to local residents and business. Adding unnecessary costs to families is never a good thing, especially given the current economic climate. Again, thank-you for your support of these bills.

Sincerely,

Louis E. Muench
President, Louie's Finer Meats, Inc.

WISCONSIN STATE LEGISLATURE

FORWARD

Testimony of Mark A. Borchardt, PhD, regarding SB19 and AB23 (to prohibit DNR from requiring a municipal water system to provide continuous disinfection of the water that it provides, unless continuous disinfection is required under federal law.)

March 30, 2011

My name is Mark Borchardt. I am a Research Microbiologist with more than 30 years of research experience. My specialty is waterborne infectious disease, and I am the Principal Investigator of the Wisconsin Water And Health Trial for Enteric Risks (called the WAHTER Study), the key study that led to the DNR rule requiring mandatory disinfection of municipal drinking water. The study was performed while I was employed at the Marshfield Clinic, but today I am speaking on my own behalf.

The primary objective of the Wisconsin WAHTER Study was to estimate the fraction of acute gastrointestinal illness, that is vomiting and diarrhea, caused by groundwater contaminated with human viruses. The research question was similar to other medical research where one asks if a potential exposure has a health risk. For example, if people stopped smoking in Wisconsin how many fewer cases would there be of lung cancer? We asked if groundwater-borne transmission of viruses were stopped, how many fewer cases would there be of gastrointestinal illness?

To answer this question we received permission from 14 Wisconsin communities to install ultraviolet light disinfection on their municipal wells. None of these communities chlorinated. In the first study year, one-half of the communities had the UV disinfection installed and the other communities served as controls. For two 12-week periods, 40 to 70 families in every community, consisting of 1,659 people in 621 households, completed a symptom checklist and mailed this to the study team every week. In the second year, the UV disinfection units were switched so the original control communities had the UV intervention and the original intervention communities became the controls. We again tracked illness symptoms for two 12-week periods using the same families as the first year. In addition, we measured the virus levels in the households' tap water.

What did we find? First, all 14 communities had human viruses in their well water sometimes at very high levels. Using tracers of wastewater, like detergents and cholesterol, we showed the likely virus source is leaking sanitary sewers. Second, there was a very strong relationship between the levels of viruses we measured in household tap water and rates of illness in the communities. In other words, the communities that had the highest virus levels in their tap water were also the sickest. In the community with the highest virus levels gastrointestinal illness increased 87% to 2.8 episodes/person-year from 1.5 episodes/person-year when viruses were absent in tap water. Third, when the UV disinfection was in place the overall reduction in illness among the communities was 13%. In the fall of 2006, when a particularly virulent virus was present in the wells, we estimate 29% of the illness in the communities was attributable to their drinking water.

This was a Cadillac study using the best methods available. Viruses were measured by sensitive and specific DNA tests. The epidemiological study design was not observational, it was experimental; we evoked a cause, installing UV disinfection, and we measured the effect, a reduction in illness. The health data was gathered not retrospectively, it was collected prospectively every week using a standardized symptom checklist. I have heard the criticism that people have talked to their friends and maybe some nurses they know at the local hospital and no one has seen anyone get sick from the water. These anecdotes cannot compare with active disease surveillance and the data we collected from 75,000 weekly symptom checklists.

The Wisconsin Department of Administration estimates without passage of the Bills the one-time government cost to upgrade disinfection equipment is $634,800 and the annual operating cost for disinfection is $130,200. How does this compare with the costs of gastrointestinal illness? A recent study by the Centers for Disease Control and Prevention (CDC) estimates the national cost for diarrheal disease in children less than 5 years old (1). These data can be extended to American adults 18 to 54 years old because we know in this adult age group the prevalence and severity of gastrointestinal illness is not much lower than that for young children (2). Among people with acute gastrointestinal illness the CDC reports the national hospitalization rate is 0.5%, the emergency room visit rate is 1.8%, and the outpatient visit rate is 13.3%. The national median payments for gastrointestinal illness treatment by hospitalization, ER visit, and outpatient is $3135, $332, and $90, respectively. According to the DNR, the total population of the 66 non-disinfecting communities in Wisconsin is 85,000. If the baseline gastrointestinal illness rate is 1.2 episodes/person-year (the national average), then the 13% reduction measured in the WAHTER Study means a reduction of 0.16 episodes/person-year, which for a 85,000 population means 13,600 illnesses are prevented. Using the CDC numbers, the health care costs avoided is $458,000 per year!

Over a 5 year period, the cost of disinfection would be roughly $1.3 million; the healthcare costs saved would be at least $2.3 million, providing an overall savings of $1 million.

This health care cost only includes direct payment to healthcare providers. It does not include the costs of work lost either by the ill person or their caregiver nor does it include the cost of death. The estimate does not consider the most disease-vulnerable populations, the immunocompromised and elderly. The estimate does not account for the legal, social, and economic costs if non-disinfection resulted in a waterborne disease outbreak, similar to the *Cryptosporidium* outbreak in Milwaukee.

Please also recognize the Wisconsin WAHTER Study dealt with the most easily measured health outcome, acute gastrointestinal illness. The viruses we identified in the 14 communities drinking water cause a variety of acute illnesses: (e.g. fever, conjunctivitis, aseptic meningitis, hand foot mouth disease) that may be mild to severe to fatal. Although less prevalent, these viruses also cause chronic conditions that may involve the heart, the nervous system, or liver.

Based on the epidemiological data from the WAHTER Study, the many scientific studies showing widespread virus occurrence in our nation's groundwater, and the fact, widely accepted among medical professionals, that these viruses are pathogenic agents capable of causing human disease, in my professional opinion, the municipal drinking water systems that do not disinfect have a significant level of waterborne disease transmission.

1. Cortes JE, Curns AT, Tate JE, Parashar UD (2009) Trends in healthcare utilization for diarrhea and rotavirus disease in privately insured US children <5 years of age, 2001-2006. *Pediatr Infect Dis J* 28:874-878.
2. Jones TF et al. (2006) A population-based estimate of the substantial burden of diarrhoeal disease in the United States; FoodNet, 1996-2003. *Epidemiol Infect* 135:293-301.

Human Enteric Viruses in Groundwater from a Confined Bedrock Aquifer

MARK A. BORCHARDT,*,†
KENNETH R. BRADBURY,‡
MADELINE B. GOTKOWITZ,‡
JOHN A. CHERRY,¶ AND
BETH L. PARKER¶

Marshfield Clinic Research Foundation, Marshfield, Wisconsin, 54449, Wisconsin Geological and Natural History Survey, University of Wisconsin Extension, Madison, Wisconsin, 53705, and Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada

Confined aquifers are overlain by low-permeability aquitards that are commonly assumed to protect underlying aquifers from microbial contaminants. However, empirical data on microbial contamination beneath aquitards is limited. This study determined the occurrence of human pathogenic viruses in well water from a deep sandstone aquifer confined by a regionally extensive shale aquitard. Three public water-supply wells were each sampled 10 times over 15 months. Samples were analyzed by reverse transcription—polymerase chain reaction (RT-PCR) for several virus groups and by cell culture for infectious enteroviruses. Seven of 30 samples were positive by RT-PCR for enteroviruses; one of these was positive for infectious echovirus 18. The virus-positive samples were collected from two wells cased through the aquitard, indicating the viruses were present in the confined aquifer. Samples from the same wells showed atmospheric tritium, indicating water recharged within the past few decades. Hydrogeologic conditions support rapid porous media transport of viruses through the upper sandstone aquifer to the top of the aquitard 61 m below ground surface. Natural fractures in the shale aquitard are one possible virus transport pathway through the aquitard; however, windows, cross-connecting well bores, or imperfect grout seals along well casings also may be involved. Deep confined aquifers can be more vulnerable to contamination by human viruses than commonly believed.

Introduction

Confined aquifers are permeable water-bearing geologic formations (i.e., sand, gravel, fractured rock) that are bounded by lower-permeability geologic formations called aquitards. Two broad categories of aquitards exist: unlithified (non-rock) aquitards composed of clay or silt-rich deposits and indurated (rock) aquitards such as shale, siltstone, quartzite, carbonates, and igneous rocks. Confined aquifers are the primary source of water for many municipalities throughout the world. Municipalities often assume low-permeability aquitards provide barriers to flow, limiting the migration of contaminants into the aquifer. However, aquitard integrity can be compromised by features such as fractures, erosional or depositional windows, and incomplete lateral extent, all of which can provide avenues for aquifer contamination. There may also be anthropogenic pathways such as improperly abandoned or cross-connecting wells. Cherry et al. (*1*) provide a review of aquitard science and point out that the capability of an aquitard to limit the transmission of contaminants depends strongly on the type of contaminant. For example, solutes have much less propensity for transmission than dense nonaqueous phase liquids (DNAPLs). Little is known about virus migration through aquitards.

Among the many waterborne pathogens of humans, enteric viruses have the greatest potential to move deep into the subsurface environment, penetrate an aquitard, and reach a confined aquifer. Enteric viruses are extremely small (27–75 nm), readily passing through sediment pores that would trap much larger pathogenic bacteria and protozoa. Adsorption to sediment grains is the primary virus removal mechanism, although the strength of the adsorptive forces depends on sediment and water chemistries, and viruses may still be transported some distance. Several recent studies have demonstrated widespread occurrence of viruses in domestic and municipal wells in the United States (*2–5*). Approximately half of waterborne disease outbreaks attributable to groundwater consumption in the United States are presumed to have a viral etiology (*6, 7*). Disease outbreaks related to groundwater contaminated by viruses have also been documented in other parts of the world (*8, 9*). The U.S. Environmental Protection Agency (EPA) has listed several viruses on its drinking water Contaminant Candidate List, emphasizing that waterborne viruses are a research priority (http://www.epa.gov/safewater/ccl/index.html).

Although the vulnerability of groundwater to virus contamination is now recognized, the occurrence of viruses in confined aquifers has not been explicitly investigated. In the most geographically extensive survey of groundwater virus contamination in the United States, Abbaszadegan et al. (*2*) sampled 448 groundwater sites in 35 states and found that 141 sites (31.5%) were positive for at least one virus type. Whether any of these samples were from confined aquifers is not noted in the study. Powell et al. (*10*) used multilevel piezometers to take depth-specific samples from five deep sandstone aquifers in the U.K., one of which was overlain by thin siltstone and mudstone strata. In this aquifer, samples from a depth of 91 m were positive for coliphages, coliform bacteria, fecal streptococci, and clostridia spores, but human viruses were not present.

The objective of the present study was to evaluate the occurrence of human viruses in the confined Mount Simon sandstone aquifer. In much of south central Wisconsin, the Mount Simon aquifer is approximately 75 m deep and overlain by regionally extensive shale known as the Eau Claire aquitard. Local water utilities routinely case municipal supply wells through the Eau Claire aquitard, assuming that it protects water in the underlying Mount Simon aquifer from pathogens. Although pathways allowing pathogen movement through aquitards have been suspected in aquitard assessments, strong evidence is rare in groundwater studies.

Experimental Section

Site Geology and Hydrogeology. Groundwater was sampled from municipal wells drawing water from the Mount Simon aquifer in Madison, WI, population 220 000 (Figure 1). The

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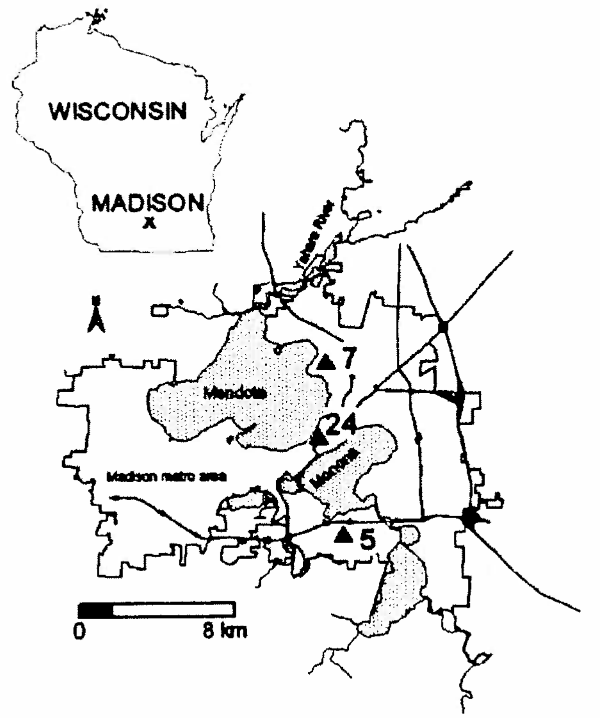

FIGURE 1. Location of study area in south-central Wisconsin. Inset shows the three wells tested in the Madison metropolitan area.

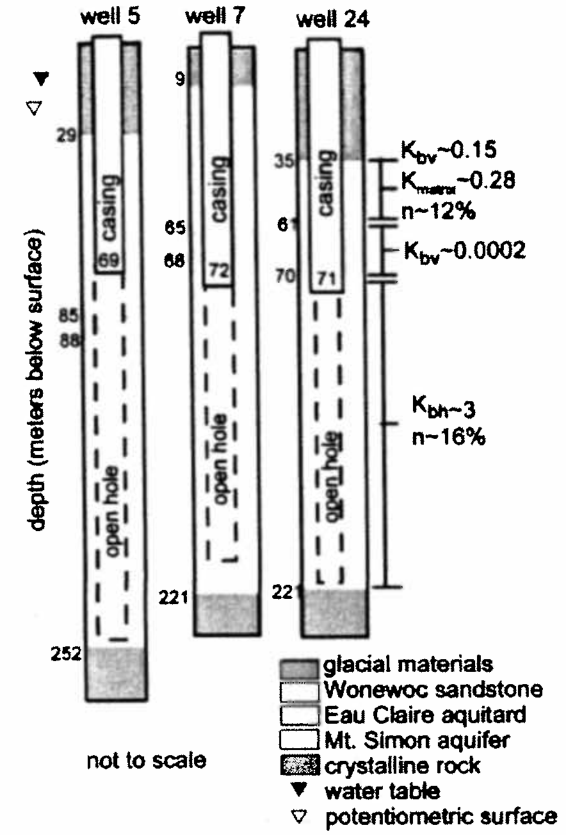

FIGURE 2. General hydrostratigraphy and construction of the three study wells. Reported bulk-vertical, matrix, and bulk-horizontal conductivities (K_{bv}, K_{matrix}, and K_{bh} respectively, in m/day) and porosity values (n) are from other studies of the regional aquifer (see text).

Eau Claire aquitard occurs about 65 m below ground surface and consists of clayey to sandy siltstone with thin laminae of fine-grained siltstone and shale units. It separates sandstone of the underlying Mount Simon aquifer from an upper unconfined aquifer consisting of glacial deposits underlain by the Wonewoc sandstone (*11*) (Figure 2).

Madison has 19 production wells of which three wells, 5, 7, and 24, were selected for this study. Wells 7 and 24 are located in highly urbanized areas in the center of the city, 970 and 480 m away from the shore of Lake Mendota, respectively (Figure 1). Well 5 is located in a suburban area on the southern boundary of Madison and is adjacent to the municipal sewage treatment plant. Each well produces 3700–7500 m^3 per day. Aquitard thickness is approximately 3 m in wells 5 and 7 and nearly 9 m in well 24. Wells 7 and 24 are cased below the Eau Claire aquitard and draw water only from the Mount Simon aquifer. The casing for the third well, well 5, does not reach the depth of the aquitard and groundwater pumped from this well is likely a mix of waters from both aquifers.

There is substantial hydraulic potential for groundwater to move downward from the glacial deposits toward the deep aquifer. Regional groundwater pumping has caused a 20 m decline in the Mount Simon aquifer's potentiometric surface in the Madison area (*12*). Bradbury et al. (*13*) measured downward vertical hydraulic gradients of 1.8 across the Eau Claire aquitard between the surficial sandstone aquifer and the Mount Simon aquifer.

Virus Sampling and Analyses. Water samples for viruses were collected monthly from each of the three wells for 10 months, from June 2003 through November 2003 and May 2004 through August 2004, for a total of 30 samples. All samples were untreated groundwater collected at the wellheads prior to chlorination. Viruses were concentrated with a 1MDS filter (CUNO, Meriden, CT) following standard virus filtration methods (*14*). The mean sample volume was 1448 L ($n = 30$, range 844–1889). Filters were eluted with beef extract, and the eluate was flocculated and concentrated with polyethylene glycol following the methods described in Borchardt et al. (*4*).

Samples were analyzed for five virus groups: enteroviruses, rotavirus, hepatitis A virus (HAV), and norovirus genogroups I and II. All viruses were detected by reverse-transcription–polymerase chain reaction (RT-PCR), followed by Southern hybridization to confirm virus identity. Borchardt et al. (*3, 4*) describe the procedures, primers, and probes. RT-PCR inhibition, which could result in false negatives, was evaluated for all samples by seeding the RNA extraction concentrates with a Norwalk virus RNA internal standard. Inhibition was mitigated by diluting the extraction concentrate 1:5 or 1:10 with nuclease-free water. False positives from virus or amplicon contamination of the samples were avoided by including negative controls for the filter eluent, RNA extraction step, and RT-PCR and hybridization reagents (*3, 4*).

Samples that were enterovirus positive by RT-PCR were further evaluated for enterovirus infectivity by cell culture following methods previously described (*4*). Cultures were observed for 14 days for viral cytopathic effect (CPE), then aliquoted into new cultures for another 14 day observation period to confirm the first passage results. In addition, after the first 14 day passage, an aliquot of each of the removed cell sheets was analyzed for viral RNA (positive strand) following the same RT-PCR procedures used for the water samples. The same aliquot was also analyzed for negative-strand RNA, following the method of Cromeans et al. (*15*), because it is diagnostic for replicating enteroviruses. Enteroviruses were identified to serotype by nucleotide sequencing following the method of Ishiko (*16*), a method used previously to identify enterovirus isolates from groundwater (*4*).

TABLE 1. Enterovirus Detection Results for Three Drinking Water Wells in Madison, Wisconsin

well	positive/ total	positive sample date	enterovirus identity	BLAST search[a] % identity[b]	BLAST search[a] E-score[c]
5	0/10				
7	4/10	Sept 24, 2003	coxsackievirus B3	100	0.0
		June 30, 2004	echovirus 18	100	0.0
		July 28, 2004	echovirus 18	100	0.0
		Aug 25, 2004	poliovirus sabin 1	100	0.0
24	3/10	Sept 24, 2003	echovirus 9	98	2×10^{-96}
		Nov 19, 2003	coxsackievirus B3	99	0.0
		July 28, 2004	coxsackievirus B1	98	6×10^{-99}

[a] Sequences were submitted for a BLAST search of the GenBank sequence database at the National Center for Biotechnology Information web site. [b] Percent identity is the degree of invariance between the query sequence and the most closely matching sequence posted in the database. [c] E-score is the expected number of better matches with the query sequence that occur in the database by chance. The lower the E-score the better the match.

Isotope Sampling and Analyses. Wells were sampled twice for the isotopes deuterium (^2H), tritium (^3H), and oxygen-18 (^{18}O). Isotope samples were analyzed at the University of Waterloo, Ontario, Environmental Isotope Laboratory. In addition, one sample from well 24 was tested for low-levels of tritium at the University of Miami, Florida, Tritium Laboratory. Deuterium was determined by manganese reduction; oxygen-18 was determined by mass spectrometry on CO_2 gas. Tritium was determined by liquid scintillation counting on enriched samples (University of Waterloo) and distillation followed by electrolytic enrichment and low-level counting (University of Miami). Tritium results are reported in tritium units (TU; 1 TU equals 1 tritium atom in 10^{18} atoms of hydrogen). Deuterium and oxygen-18 results are reported as per mil (‰) differences from the concentrations in Vienna Standard Mean Ocean Water.

Results and Discussion

Virus Analyses. Of the 30 well water samples collected for virus analyses, seven (23%) were positive for enteroviruses (Table 1). Other enteric viruses tested (rotavirus, HAV, and noroviruses) were absent in all samples. The seven enterovirus-positive samples were taken from wells 7 and 24, which are both cased through the Eau Claire aquitard and draw water from the confined Mount Simon aquifer. The well water samples were enterovirus positive in the summer and autumn months, the same time of year when the incidence of enterovirus infections and their occurrence in wastewater peaks in Wisconsin (*17*). Well 5 was virus-negative throughout the 10 month sampling period, even though this well bore is open to both the upper, unconfined aquifer and the Mount Simon aquifer. Viruses may have been absent because there was not a nearby source of human fecal waste released into the environment.

There are numerous reports of enteroviruses identified in groundwater in the United States, primarily using cell culture detection methods (*7, 18*). Three recent studies used the RT-PCR method similar to the present study. Abbaszadegan et al. (*2*) investigated 448 wells in 35 states and found that 68 wells (15.2%) were positive for enteroviruses. Six of these positive wells drew water from sandstone aquifers. Fout et al. (*5*) analyzed 321 monthly samples taken over a year from 29 wells located in the continental United States, Puerto Rico, and the Virgin Islands and found 15 samples (5%) and 11 wells (38%) were enterovirus-positive. Borchardt et al. (*4*) tested 48 samples taken monthly over a 1 year period from six shallow wells (<49 m) providing drinking water to a single municipality in Wisconsin. Twenty samples (42%) and six wells (86%) were positive for enteroviruses. In the present study, 23% of the well water samples were enterovirus-positive, a proportion similar to that in the previously published work.

Enteroviruses are common human pathogens estimated to cause 30–50 million infections annually in the United States (*19*). The prefix "entero" is descriptive of their host infection route from entry via ingestion, passage through the enteric system, and excretion in the host's feces. The viruses are small (30 nm diameter) and icosahedral shaped. There are 64 enterovirus serotypes. The diseases associated with enterovirus infections are wide-ranging and include the common cold, nonspecific fever, diarrhea, and a variety of severe illnesses involving respiratory, cardiovascular, or neurologic systems. The most common neurologic disorder is aseptic meningitis, which is estimated to result in 50 000 hospitalizations each year in the U.S. (*19*). How many enterovirus infections are attributable to waterborne transmission is unknown, and for this reason, enteroviruses have been placed on the EPA's drinking water Contaminant Candidate List.

Five enterovirus serotypes were identified in the seven positive samples (Table 1). Two of the identified serogroups, coxsackieviruses and echoviruses, are ubiquitous in the U.S. population and have been previously reported in groundwater (*7*). However, finding the poliovirus vaccine strain Sabin 1 in groundwater was unexpected. Oral administration of the vaccine was discontinued in the U.S. in 2000 to reduce the amount of poliovirus released into the environment via fecal shedding and the possible reversion to wildtype virulent strains. Of the three oral poliovirus vaccine strains, the Sabin type 1 is considered the most stable (*20*). Circulation of vaccine-derived strains in population subgroups has been reported (*21*). A large population of foreign students and their families live in the Madison area to attend the University of Wisconsin. Many of the foreign students' home countries still use the oral vaccine, making them a conceivable source for the poliovirus found in the groundwater. Laboratory contamination of the groundwater samples is highly unlikely because this vaccine strain has never been used in the laboratory where the samples were analyzed.

The seven enterovirus-positive samples were analyzed by cell culture for infectivity. All seven were negative for cytopathic effect. However, five of the CPE-negative cultures were positive by RT-PCR despite being incubated for 14 days at 37 °C and being diluted by washing and refeeding the cell sheets on day 7. This suggests the viruses were replicating but not producing CPE, which is not uncommon for environmental isolates of enteroviruses (*22, 23*). Another explanation is the viruses did not replicate, but there were enough virions present in the initial cell culture inoculum that they remained adsorbed and intact on the cells until detected by RT-PCR 14 days later.

One of the five RT-PCR positive cultures was positive for the replicating negative RNA strand. Enteroviruses are positive-sense single-stranded RNA viruses. The comple-

TABLE 2. Isotope Results for Three Drinking Water Wells in Madison, WI

well	sample date	TU value	tritium method[a]	δ^2H ‰[b]	$\delta^{18}O$ ‰[b]	chloride range[c] (mg/L)
5	June 18, 2003	1.4	enriched	−72.24	−10.65	3−4
	May 12, 2004	<6	standard	−70.65	−10.53	
7	June 18, 2003	8.9	enriched	−57.18	−8.56	9−24
	May 12, 2004	9.9	low-level counting	−57.78	−8.36	
24	June 18, 2003	<0.8	enriched	−60.21	−8.88	4−5
	May 12, 2004	<0.8	enriched	−60.20	−8.80	
	May 12, 2004[d]	1.03	low-level counting			

[a] Enriched method analyzed at University of Waterloo, error ± 0.8 TU; standard method analyzed at University of Waterloo, error ± 0.8 TU; low-level method analyzed at University of Miami, error ± 0.09 TU. [b] Precision of ^2H analysis is ± 0.8‰; precision of ^{18}O analysis is ± 0.2‰. [c] Chloride samples collected between 1993 and 1999 and reported by the WI DNR (*26*) [d] Duplicate tritium samples were collected on May 12, 2004.

mentary negative strand is only produced when the virus is replicating. Detecting the negative strand is definitive evidence that the virus in this sample, an echovirus 18 collected from well 7, was infectious.

Isotope and Chloride Analyses. Isotopic compositions and chloride concentrations indicate that groundwater in the sampled wells is relatively young and probably did not originate as recharge from the nearby lakes. The isotopes tritium, oxygen-18, and deuterium have long been used as natural tracers in hydrologic studies to gain insights about groundwater age and origin (*24*). Atmospheric tritium increased dramatically following atomic weapons testing in the 1950s and 1960s. Radioactive decay has reduced the tritium content of groundwater (half-life 12.4 years) recharged over 40 years ago to generally no more than about 0.1 TU today. The tritium concentrations found in well 7 are substantial (Table 2) and in the range of recent precipitation, indicating that most or all of the water from this well entered the groundwater system since the mid-1950s, and possibly much more recently. The other two wells, 5 and 24, contained low but detectable tritium values (Table 2), likely indicating a mixture of post- and pre-1950s water or strong influence of diffusion driven mass transfer of tritium from fractures into the rock matrix (*25*).

Chloride concentrations in the three wells parallel the tritium results (Table 2). Background nonanthropogenic chloride values for the Mount Simon aquifer are less than 1 mg/L, but the concentrations in the three wells sampled are greater than 1 mg/L, with well 7 being the highest (*26*), consistent with tritium. The chloride is likely derived from road salting; substantial road salting in Madison began in the 1950s, and chloride concentrations in the lakes and in some Madison wells have gradually increased since then.

The presence of tritium and chloride in the Mount Simon aquifer is consistent with what is known about the hydrogeologic conditions beneath Madison. Long-term pumping from the Mount Simon aquifer has caused downward flow of recharge water from the surface through the glacial deposits and then through the upper Wonewoc sandstone to the top of the Eau Claire aquitard. Simple one-dimensional advective flow calculations based on Darcy's Law and characteristics of the Wonewoc sandstone indicate that substantial tritium and chloride arrival at the top of the Eau Claire aquitard sometime between a few years and a few decades ago is hydraulically reasonable. Penetration of tritium and chloride across the Eau Claire aquitard is also reasonable. Aquitards commonly contain fractures that provide preferential groundwater flow pathways (*1*). Taken together, the tritium and chloride data show that the bulk of the groundwater pumped from well 7, and some of the water from wells 5 and 24, recharged the aquifer and penetrated beneath the Eau Claire aquitard anytime within the last 30 or 40 years, even possibly within a year or two, and such rapid bulk water travel times are consistent with simple Darcy's Law estimates of advective travel times. However, these travel times are too long to explain the presence of relatively ephemeral viruses detected below the aquitard in wells 7 and 24.

Although on a regional scale, significant recharge probably occurs as downward leakage from the Madison Lakes, the stable isotope compositions show no evidence that water in the three wells originated in the lakes. Stable isotope ratios of water are conservative in aquifers at low temperature, but surface water becomes isotopically fractionated when the humidity is less than 100%. Evaporation preferentially enriches surface water in ^{18}O relative to ^2H. As a result, $\delta^{18}O$ and δ^2H ratios can be used to identify groundwater sources and understand surface water interaction with wells (*27*). The ratios of oxygen-18 to deuterium for all three study wells did not deviate substantially from the ratio defined by the meteoric water line established for Madison by Swanson et al. (*28*). Water samples from the Madison lakes Mendota, Monona, and Wingra, collected in late June 1995, gave values that were much different than those from wells 7 and 24 (i.e., $\delta^{18}O$ ranges between −5.57 and −6.29 ‰ for the lakes). These values, characteristic of water having undergone free-surface evaporation, did not appear in the sampled wells.

Viruses in the Mount Simon Aquifer. The detection of viruses in the confined Mount Simon aquifer beneath the shale aquitard breaks with conventional wisdom and is considered surprising. Or is it? For viruses to be present, there must be pathways allowing rapid transport into the deep aquifer. Transport times must be rapid because virus survival time in the subsurface is on the order of a few weeks to a few years, depending on virus type, water chemistry, microbial interactions, and groundwater temperature (*29*, *30*). The aquifers beneath Madison have an annual mean temperature of 10 °C, favoring longer virus survival times. Nevertheless, the matrix permeability of the shale is too small to allow virus transport within even the upper time limit of virus survival, and therefore, the possibilities for virus transport through the aquitard must involve preferential pathways.

There are four conceptual pathways into the Mount Simon aquifer. Transport vertically through the upper sandstone aquifer followed by (1) transport through fractures in the Eau Claire aquitard, (2) transport through depositional or erosional stratigraphic windows in the Eau Claire aquitard, or the anthropogenic pathways, (3) transport down open wells or boreholes that cross-connect the upper aquifer with the Mount Simon aquifer across the Eau Claire aquitard and (4) transport across the Eau Claire aquitard along the pumping well annulus that is damaged, deteriorated, or has poorly installed grout or breaches in the well casing.

All four pathways must begin with a virus source, and within the Madison city limits, significant human fecal waste is only present in sanitary sewers. Wastewater influent in Wisconsin can contain hundreds to thousands of culturable enteroviruses per liter (*17*). Sanitary sewers may leak, depending on age and pipe material (*31*). Two of the three study wells, wells 7 and 24, are located in densely developed urban areas with numerous sewer lines in proximity. The sewer lines are buried 2–9 m below the surface, a depth not far above the water table which is at 10 m.

Viruses following pathways 1 or 2 would need to traverse four segments in the natural hydrogeological setting: (1) through the glacial deposits to the top of the upper Wonewoc sandstone, (2) through 26–56 m of Wonewoc sandstone to the top of the Eau Claire aquitard, (3) through 3–9 m of shale aquitard to the top of the Mount Simon sandstone, and (4) through the Mount Simon sandstone to the well. The first segment is likely rapid because the glacial deposits include permeable coarse sand and gravel beds, and moreover, in the area surrounding well 7 the top of the Wonewoc sandstone is only 9 m below ground surface. Bounding calculations were performed using Darcy's Law with available hydrogeologic parameters (Figure 2) to assess the reasonableness of the next three transport segments.

The second transport segment is the Wonewoc Formation, a clean, poorly cemented, fine- to medium-grained sandstone. This sandstone's estimated bulk vertical hydraulic conductivity (K_{bv}) (*12*) is similar to its measured matrix hydraulic conductivity (B.L. Parker, written communication), which in conjunction with the poor cementation, suggests that the Wonewoc Formation is dominated by matrix flow at wells 5, 7, and 24. The mean matrix effective porosity of the Wonewoc sandstone is 12% (range 8–17%, $n = 7$) (Parker, written communication). On the basis of these parameters and the vertical gradient induced by pumping (0.02–0.15) (*13*), the estimated travel time through the Wonewoc sandstone is a few months to a few years. Measured pore throat diameters in the Wonewoc are on the order of tens of microns (Parker, written communication), hundreds of times larger than enterovirus diameters, suggesting viruses could easily physically pass through the sandstone matrix. Cores of the Wonewoc appear as loose sand when removed from the drilling rig, and field experiments have shown virus transport in sand can be rapid (*32*).

For viruses to cross the Eau Claire aquitard, the third transport segment, preferential pathways such as fractures or windows must be present. Although fractures in the Eau Claire could not be directly observed, fractures commonly occur in shaley geologic materials (*1*). Field measurements of the bulk K_v of the Eau Claire aquitard have not been conducted; however, Krohelski et al. (*12*) estimated it to be 0.0002 m/day and found that a regional scale numerical model for groundwater flow calibrated well with this value. This value for bulk K_v is orders of magnitude larger than typical matrix values for shale (*33*), and the presence of vertical fractures is one reasonable explanation for this much larger value. Hart et al. (*34*) showed that relatively widely spaced vertical fractures of moderate aperture (50 μm) could account for a two order-of-magnitude increase in bulk over matrix K_v for a shale aquitard in eastern Wisconsin.

There are many examples of rapid transport of colloid particles through fractured materials. McKay et al. (*35*) demonstrated that the viruses PRD-1 and MS-2 move through a fractured clay with apertures ranging between 5 and 30 μm and bulk horizontal hydraulic conductivity ranging between 2×10^{-10} and 2×10^{-6} m/s. The virus velocity was 2–5 m/day, 100–200 times faster than the conservative tracer bromide. McKay et al. (*36*) found that transport velocities of bacteriophage through a column of fractured shale saprolite were similar to velocities calculated using aperture estimates derived from the cubic law. In a field-scale experiment in the same material, McKay et al. (*37*) measured transport velocities for colloids of 5–200 m/day under normal gradient conditions.

Depositional or erosional stratigraphic windows also could provide a route through the Eau Claire aquitard. Recent studies show that the hydraulically resistive part of the Eau Claire formation underneath Madison actually has aquitard characteristics much thinner (0.5–7 m) than previously thought (*13*) and may be entirely absent in some areas. The deep Madison lakes, Mendota and Monona, are depressions formed by erosion through the aquitard during the Pleistocene glaciation, and smaller erosional windows could exist elsewhere in the shale.

Once across the Eau Claire aquitard, virus transport through the Mount Simon sandstone into the pumping wells is feasible. Flow in the Mount Simon likely occurs in the matrix in poorly cemented sections and in bedding parallel fractures in the firmly cemented sections. Vertical and horizontal fractures in the Mount Simon sandstone are visible in optical borehole logs from several Madison wells. The bulk horizontal hydraulic conductivity of the Mount Simon aquifer is approximately 3 m/day (*12*), and the mean effective porosity is 16% (range 8–23%, $n = 4$) (B.L. Parker, written communication). Therefore, velocities for matrix flow through the Mount Simon aquifer range from 69 to 690 m/year for horizontal gradients of 0.01 and 0.1, respectively. Transport velocities in fractures could theoretically be 10–1000 times faster than matrix flow.

The third and fourth conceptual pathways are anthropogenic and specific to historical well construction and abandonment procedures in Madison. Whether any abandoned open well or boreholes remain in Madison is unknown, although they are believed to exist. Modeling studies have shown that entire contaminant plumes can be transported from an upper aquifer, through an aquitard, and into the underlying aquifer by cross-connecting wells or boreholes (*38*). In addition, Hart et al. (*34*) showed that a relatively small number of cross-connecting wells or boreholes could create an order of magnitude or more difference between the vertical matrix and vertical bulk hydraulic conductivities in a shale aquitard.

Last, faulty annular well seals could be responsible for cross-connecting the upper aquifer with the Mount Simon aquifer. Drilling records for virus-positive wells 7 and 24 show they were constructed according to accepted practice, although aging (well 7, 68 years; well 24, 27 years) may have deteriorated the well grout or casing. Meiri (*39*) described where a faulty well seal was responsible for contaminant transport across a clayey aquitard. These anthropogenic pathways could transport viruses to the wells, but the elevated tritium and chloride levels suggest there must be larger inputs of recent recharge to the Mount Simon aquifer that cannot be accounted for by leaky well seals.

The vertical travel distance from the sewers down to the Mount Simon aquifer is 60–65 m, which is not an unrealistic transport depth. Viruses readily move to depths of 30 m, and a depth as great as 67 m has been reported (*40*). A private domestic well cased 52 m in fractured dolomite was positive for enterovirus, rotavirus, and norovirus (*3*). In an urban area in the United Kingdom, Powell et al. (*10*) collected depth-specific samples from an aquifer overlain with several mudstone bands. Beneath these bands at a depth of 47 m, samples were positive for coliphages, coliforms, fecal streptococci, and culturable enterovirusues. The study investigators suggest this microbial contamination resulted from leaky sewers with microbial transport along natural fissures (fractures) and bedding planes.

Determination of the exact transport pathway for viruses to reach the study wells is beyond the scope of the present study. We have shown there are several plausible pathways. On the basis of current knowledge of the local hydrogeological setting, it is not necessary to invoke anthropogenic pathways to account for the viruses in the Mount Simon aquifer. Detecting viruses in wells 7 and 24 is, perhaps, not so surprising after all.

Implications for the Drinking Water Industry. Hydrogeologists and water utility managers often assume that deep municipal wells, such as those sampled in this study, are protected from microbial contaminants originating at or near the land surface. This is particularly true for wells cased through laterally extensive aquitards composed of clay or shale into deep aquifers. It has been believed that vertical transport times through aquitards were too long and microbial survival time too short for microbial contaminants to reach these confined aquifers (*41*). In the present study, the presence of human enteric viruses in the confined Mount Simon aquifer indicates that viruses are able to penetrate through or otherwise bypass the overlying Eau Claire aquitard. The understanding of hydrology and solute contaminant transport in fractured rock is in its infancy and even less is known about virus transport in fractured rock. The most robust microbial transport models based on colloid filtration theory cannot yet reliably predict virus occurrence in a field setting (*42*). The safest assumption from a public health perspective is that drinking water drawn from a confined aquifer is as vulnerable to microbial contamination as an unconfined aquifer and requires a similar level of disinfection.

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Groundwater-Borne Viruses and Illness Risk in Wisconsin

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USDA-Agricultural Research Service

National Caucus of Environmental Legislators' 9th Annual Midwest/Great Lakes Forum
December 4, 2010

Wisconsin's Groundwater

- Groundwater supports the water needs of 2/3s of WI residents and 1/3 of WI businesses and industries.
- From 1985 to 2000 WI groundwater demand increased to 804 from 570 million gallons per day.
- Water table drawdown over the past century: Dane County = 60 ft; Green Bay region = 300 ft; Waukesha County = 450 ft.
- As groundwater becomes less available groundwater quality takes on added importance

Data obtained from the WI DNR web site

Waterborne Disease Outbreaks in the USA

- From 1971 to 2006 there were nearly 750 outbreaks associated with an infectious agent in drinking water; 60% of the outbreaks were attributable to groundwater
- Pathogen in about 50% of outbreaks is unknown and assumed viral

Summarized from CDC reports, e.g., MMWR 2006, 55(SS12):31-58

Human viruses are present in...

Incidence of Enteric Viruses in Groundwater from Household Wells in Wisconsin

Private domestic wells

Human Enteric Viruses in Groundwater from a Confined Bedrock Aquifer

Even in a confined aquifer

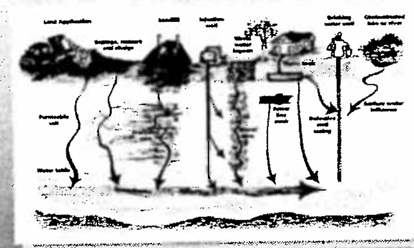
Vulnerability of Drinking-Water Wells in La Crosse, Wisconsin, to Enteric-Virus Contamination from Surface Water Contributions

Municipal wells in an alluvial aquifer

Virus Subsurface Transport Potential

- Small size (~ 50 nm) and negative charge favor movement through soil
- Survivability favored by low temp, moisture, and absence of UV light
- Documented transport: penetration as deep as 72 m, horizontal migration up to 1600 m

Virus Sources and Infiltration Routes into Groundwater



Modified from Keswick and Gerba 1980

Enteric Viruses – Clinical Significance

Wisconsin WAHTER

- **Enteroviruses:** fever, "summer cold", diarrhea, hand, foot, mouth disease, conjunctivitis, meningitis, myocarditis, poliomyelitis, diabetes? chronic fatigue syndrome?
- **Rotavirus:** severe diarrhea and vomiting, 50,000 hospitalizations/year in US
- **Hepatitis A virus:** gastroenteritis, hepatitis, fatality rate of 2.7% in people > 49 years of age
- **Noroviruses:** gastroenteritis, "the flu"
- **Adenoviruses:** diarrhea, acute respiratory illness, pneumonia, conjunctivitis, neurological diseases, obesity?

Health Risk or Non-Issue?

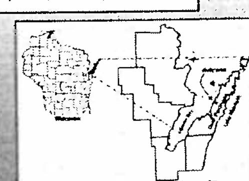
- So viruses are present in public water supply and domestic wells …
- Does it matter?
- Is there any effect on public health?

ground water

Case Study/

Norovirus Outbreak Caused by a New Septic System in a Dolomite Aquifer

by Mark A. Borchardt, Kenneth R. Bradbury, E. Calvin Alexander Jr., Rhonda J. Kolberg, Scott C. Alexander, John R. Archer, Laurel A. Braatz, Brian M. Forest, Jeffrey A. Green, and Susan K. Spencer



Wisconsin WAHTER Study

Funded by the US EPA STAR Program

Study Period: 2005 – 2009

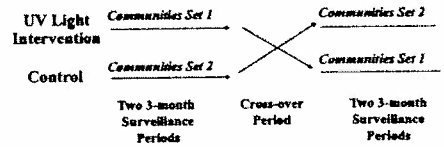
Collaborators include UC-Davis and UW-Madison

Study Objectives

1. Determine the association between tap water virus concentrations and community illness rates
2. Estimate the risk of acute gastrointestinal illness (AGI) from drinking municipal water from groundwater sources
3. Accounting for any risk contributed by groundwater, estimate the AGI risk contributed solely by contaminated distribution systems
4. Determine the association between viruses in distribution systems and utility operation and maintenance procedures

Wisconsin WAHTER Study Design

Intervention trial in 14 groundwater-source communities



WAHTER Study Participating Communities

Populations: 1,200 – 8,300

Number Wells: 2 – 5

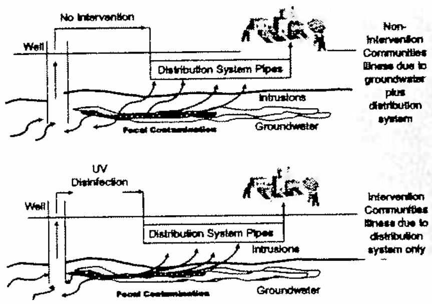
Pumpage: 0.13 – 2.1 MGD

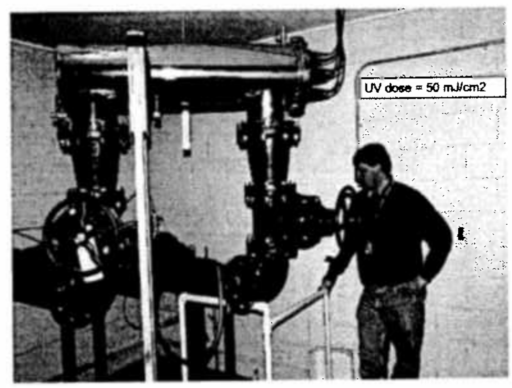
Hydrogeology: sand, sandstone, limestone

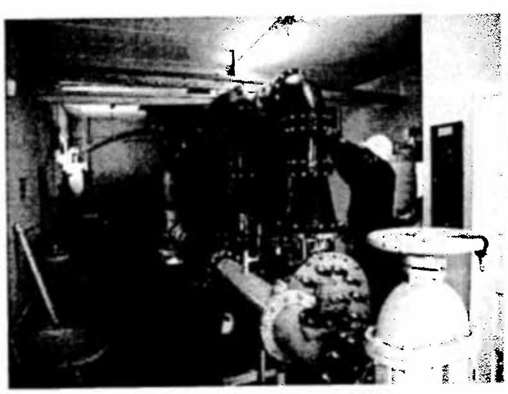
No surface water influence

No disinfection

UV Intervention Effect







Epidemiological Study Design

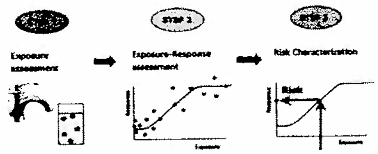
- Acute gastrointestinal illness (AGI) surveillance for four 12 week periods, spring and autumn 2006 and 2007
- AGI defined as ≥ three episodes loose watery stools OR ≥ one episode vomiting in 24 hour period
- Eligibility: family served by study community's water system and have at least one child 6 months to 12 years old
- Exclusions: chronic GI illness; child attends daycare or school outside of community > 20 hrs/week
- Participants submitted an illness symptom checklist every week

Participating Households' Characteristics

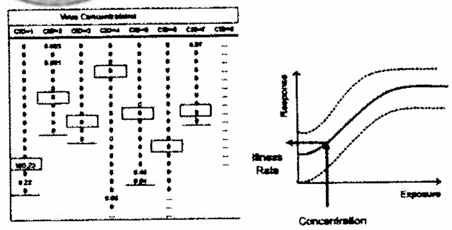
Characteristic	Number	%
Household size (no. of persons)		
2	17	(3)
3	160	(26)
4	248	(40)
5	136	(22)
≥6	61	(10)
Residence type		
Single family home	572	(92)
Apartment or condo	43	(7)
Other	6	(1)
Faucet or plumbing filtering device		
Yes	73	(12)
No	547	(88)
Don't know	1	(<1)
Primary drinking water source		
Municipal	1546	(93)
Bottled water	52	(3)
Other	1	(<1)
Missing	54	(3)

- **Beginning enrollment: 621 households**
- **Ending enrollment: 440 households**
- **Beginning enrollment: 1,079 children, 580 adults**
- **Ending enrollment: 765 children, 413 adults**

Risk Assessment Overview

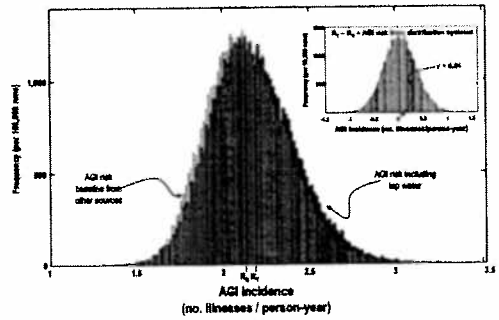


STEP 3 Risk Characterization



Monte Carlo: repeat 100,000 times to account for variability in concentrations and error in exposure-response relationship.

Distribution System Risk – Approach 1 With UV



Distribution System Risks Varying the Virus Concentration - Illness Relationship

Approach 1 – With UV

Virus Concentration – Illness Relationship	Median Attributable Risk[a] (AGI episodes/person-year	Attributable Risk %[b]
All viruses, All ages	0.031	1.8
All viruses, Adults	0.067	3.9
Enteroviruses, Adults	0.044	2.6
GI Norovirus, All ages	0.024	1.4
GI Norovirus, Adults	0.036	2.1
GI Norovirus, Children	0.018	1.1
GI Norovirus, Child<5	0.043	1.6

a. Number of Monte Carlo runs: n=100,000.
b. Denominator AGI incidence from the simulated "No UV" periods when contributions to illness included distribution system, well water, and other sources (e.g., person to person). Denominator varies by age group.

- AGI incidence higher than zero in all scenarios
- Low attributable risk %

Does Groundwater-borne Illness Risk Meet EPA Standards?

- Acceptable EPA risk for waterborne disease is 1 infection in 10,000 people/year
- Assume every infection leads to an illness, then the acceptable illness rate is 0.0001 illness/person-year
- In the fall of 2006 the WAHTER Study measured 0.44 illness/person-year in children < 5 years old that was attributed to groundwater
- 4,400 times higher than EPA acceptable risk

WI Drinking Water Code Change

- WI Code NR 810 revised to require disinfection of municipal water supplies
- Public hearings completed October, 2009
- DNR Board reviewed and approved on April 28 2010
- Legislative review by Senate Committee on Environment and Natural Resources, and Assembly Committee on Natural Resources
- Final Rule filed with the Legislative Reference Bureau

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Questions?

Comments?

WISCONSIN STATE LEGISLATURE

15+3

Testimony of Kenneth R. Bradbury, PhD, regarding SB19 and AB23 (to prohibit DNR from requiring a municipal water system to provide continuous disinfection of the water that it provides, unless continuous disinfection is required under federal law.)

March 30, 2011

Good morning. My name is Kenneth Bradbury. I am a professional groundwater geologist with the Wisconsin Geological and Natural History Survey, UW-Extension. I have a PhD in hydrogeology and over 30 years of experience in water resources issues, including water quality studies, in Wisconsin. Over the last several years I have helped inform the legislature on groundwater issues on a number of occasions, and continue to be available as a resource. I am here today to offer some perspective on this proposed legislation.

Of all the means that society uses to protect and improve human health, disinfection of water supplies is among the simplest and most cost-effective. Historically, water disinfection has led to enormous improvements in the human condition throughout the world. One only needs to travel to an undeveloped country where "you can't drink the water" to be reminded how we take good water quality for granted here in Wisconsin.

Over the past decade scientists in Wisconsin (including me) have conducted research on the presence of infectious viruses in groundwater. Results of these studies have been, and continue to be, published in scientific papers, but can be summarized simply as follows:

1. Human viruses, probably originating from sewage effluent, are present in water pumped from municipal wells in many parts of Wisconsin, including right here in Madison. These viruses can sometimes be infectious, and can cause gastro-intestinal illness in people.

2. These viruses are not the same as the bacteria commonly tested for by municipal water utilities; the absence of bacteria does not necessarily indicate that water is virus-free. Most water utilities do not test for viruses because virus testing is not required and only recently became available.

3. A recent EPA-funded study on 14 small communities in Wisconsin has shown that about 15% of **current** gastro-intestinal illness in these communities can be directly attributed to consumption of non-disinfected municipal water.

4. Disinfection of water is relatively easy and can be accomplished by several methods including chlorination, ultra-violet light, reverse osmosis, or ozone treatment.

Currently, at least 66 Wisconsin communities do not disinfect municipal drinking water supplies. In spite of our natural desire to think of subsurface water resources as "pure", our research shows that this is not the case, especially in populated areas where many contamination sources exist.

Based on this work, we have been recommending that all municipal water systems disinfect the water they serve out to consumers.

For this reason I cannot recommend passage of the proposed legislation in SB19 and AB23.

Water disinfection is a good idea, is sound public policy, and will improve the health of Wisconsin citizens.

I am happy to respond to any questions you may have and offer our assistance to the legislature as you consider these issues.